10/579890
IAP9 Rec'd PCT/PTO 18 MAY 2006

SUBSTITUTE SPECIFICATION: CLEAN COPY

10/579890
IAP9 Rec'd PCT/PTO 18 MAY 2006

METHOD FOR DETERMINING DETECTION THRESHOLDS DEPENDENT ON TIRE PROPERTIES FOR THE IMPROVED DETECTION OF A LOSS OF TIRE PRESSURE IN AN INDIRECTLY MEASURING TIRE PRESSURE MONITORING SYSTEM

BACKGROUND OF THE INVENTION

[0001] The present invention relates to a method for determining detection thresholds dependent on tire properties for the improved detection of a loss of tire pressure in an indirectly measuring tire pressure monitoring system.

[0002] It is of great significance for vehicle safety to reliably monitor the tire inflation pressure. There are different approaches how to realize tire pressure monitoring systems. The first approaches are based on a direct pressure measurement in the tire (TPMS). Tire pressure monitoring systems with direct pressure measurement of this type, as disclosed e.g. in DE 199 38 431 C2, monitor the tire inflation pressure on all wheels by means of pressure modules fitted in or at the vehicle wheels or tires. The pressure modules measure the respective tire inflation pressure or a value proportional to the tire inflation pressure. Usually, the tire inflation pressures measured by the pressure modules are sent by transmitters connected to the pressure modules to one or more receivers with a subsequent evaluation unit arranged at the vehicle. This direct measurement renders the system (TPMS) independent of tire characteristics (tire diameter, width of tire, summer/winter tires, etc.). Therefore, the directly measuring tire pressure monitoring system (TPMS) is able to detect tire inflation pressure loss with a high rate of precision or by way of narrow detection thresholds. It is disadvantageous in this system (TPMS) that additional devices such as pressure modules, transmitting and

receiving devices, evaluation unit, etc. are required, what renders the system (TPMS) expensive and, on account of the number of the additional devices, fault-prone.

[0003] Another system which is based on indirect pressure measurement, e.g. described in DE 100 58 140 A1, evaluates the wheel speeds or variables proportional to the wheel speeds of the individual wheels in order to detect pressure loss. Indirectly measuring tire pressure systems of this type are inexpensive and reliable because they mostly make use of the wheel speed sensors of an anti-lock system (ABS) already provided in the vehicles in order to detect the wheel speeds. It is disadvantageous in this system that the wheel speeds highly depend on the tire characteristics. In order to prevent the development of spurious alarms irritating the driver, even with different tires, e.g. when changing from usually wide base summer tires to narrow base winter tires, the detection thresholds are chosen to be wider in view of tire inflation pressure loss. However, tire inflation pressure loss is consequently indicated to the driver only at a relatively late time.

[0004] In addition, combined systems are known, from DE 100 60 392 A1, for example, which comprise a tire pressure monitoring system with direct measurement and a tire pressure monitoring system with indirect measurement. In such combined systems, e.g. the indirectly measuring tire pressure monitoring system is used to assign the pressure modules in the wheels to an installation position, for example, pressure module '1' assumes the installation position 'left front wheel', while pressure module '2' assumes the installation position 'right rear wheel', etc.

[0005] An object of the invention is to provide a method which improves the indirectly measuring tire pressure monitoring system in a combined system to such effect that the detection thresholds are adapted depending on the tire characteristics, with the result that the driver is early alerted to tire inflation pressure loss.

SUMMARY OF THE INVENTION

[0006] According to the invention, this object is achieved by a method including detecting wheel speed signals (n) of the vehicle wheels, detecting at least one directly measured tire inflation pressure (P), learning at least one reference value depending on the detected wheel speed signals (n) at a predetermined nominal tire inflation pressure (Pnominal), determining at least one coefficient (k) which describes the characteristics of at least one vehicle tire from wheel speed variations (Δn) at a tire inflation pressure variation (ΔP), and determining at least one detection threshold (S) that depends on tire characteristics for the improved detection of tire inflation pressure loss from the coefficient (k) found, from a designated critical tire inflation pressure loss (ΔPcrit) that describes a tire inflation pressure value which, when it is not reached or is exceeded, causes a warning indicating tire inflation pressure loss to be given to the driver of the vehicle, as well as from a predefined nominal tire inflation pressure (Pnominal).

[0007] Normally the rubber compound of summer tires is harder than the rubber compound of winter tires, that means that summer tires exhibit a greater rigidity of the rubber compound than winter tires. For this reason, rubber tires show greater changes in the tire rolling circumference when undergoing a pressure variation than winter tires. In so-called wide base tires, the

change in the tire rolling circumference when undergoing pressure variation is likewise greater than with narrow base tires.

[0008] According to the invention, the term 'wheel speed signal' implies both the wheel speed per se and quantities depending on the wheel rotational speed such as the wheel velocity or the rolling circumference of the wheel. Further, the term 'wheel speed signal' shall also mean a time which is required to cover a defined distance, e.g. a distance which corresponds to one or more wheel rotations. This distance can also depend on the vehicle speed, in as far as with different vehicle speeds, different times for identical or different distances are used as a basis for the calculation. For example, at a vehicle speed of 50 km/h, the time is measured which is required for two wheel rotations, while at a vehicle speed of 100 km/h the time is measured which is required for five wheel rotations.

[0009] According to the invention, the term 'coefficient k' shall refer to a value which describes the tire characteristics such as tire diameter, tire width, summer/winter tires, etc., of one or more vehicle tires. The coefficient k_{fl} refers to the tire characteristics of the left front wheel, coefficient k_{fr} refers to the tire characteristics of the right front wheel, coefficient k_{rl} stands for the tire characteristics of the left rear wheel, and coefficient k_{rr} for the tire characteristics of the right rear wheel.

[0010] Preferably, the coefficient k is determined from the wheel rotational speed n, in particular from the relative wheel speed variation $\Delta n/n$, and the directly measured tire inflation pressure P, in particular the relative tire pressure variation $\Delta P/P_{nominal}$.

[0011] In an especially preferred manner, the coefficient k is defined by a linear function in which essentially the relative wheel speed variation $\Delta n/n$ equals the product of the coefficient k and the relative tire pressure variation $\Delta P/P_{nominal}$.

[0012] In a favorable embodiment of the method of the invention, the nominal tire inflation pressure $P_{nominal}$ is adjusted by the driver.

[0013] In another preferred embodiment of the method of the invention, the directly measuring tire pressure monitoring system (TPMS) is used to check whether the nominal tire inflation pressure $P_{nominal}$ is adjusted.

[0014] Advantageously, the method of the invention is started by manual actuation of a trigger mechanism, preferably by the driver. Favorably, the trigger mechanism is a switch or a key button.

[0015] Further preferred embodiments of the method of the invention can be taken from the description below. The invention will be described in the following making reference to an embodiment.

BRIEF DESCRIPTION OF THE DRAWING

[0016] In the accompanying drawing:

[0017] The figure is a block diagram illustrating a tire pressure monitoring system.

DETAILED DESCRIPTION OF THE DRAWING

[0018] In the indirectly measuring tire pressure monitoring system, information about the wheel speeds or the rolling circumferences of the wheels is determined by evaluating wheel speed sensors. These wheel speed sensors are installed in many modern vehicles in order to furnish e.g. wheel speed data for an anti-lock system (ABS). The variation of the wheel rolling circumference depends on the tire inflation pressure and on the tire characteristics (tire diameter, tire width, rubber compound characteristics, carcass rigidity, etc.). Criteria for tire inflation pressure loss are designated by reviewing and evaluating the rolling circumferences of the wheels. To this end, detection thresholds are necessary among others, and tire inflation pressure loss is considered to prevail when these thresholds are exceeded or not reached. In this arrangement, the detection thresholds are dependent on the tire characteristics or on the type of tire mounted on the wheels. The detection thresholds and the sensitivity of the indirectly measuring tire pressure monitoring system are adapted in such a fashion that tire inflation pressure loss is detected in all types of tires approved for the vehicle, on the one hand, while spurious alarms are prevented, on the other hand. This adaptation is done by evaluating the results of measurement of one or more pressure modules of the directly measuring tire pressure monitoring system (TPMS).

[0019] As mentioned hereinabove, the indirectly measuring tire pressure monitoring system is based on wheel speed sensors. These wheel speed sensors are invariably assigned to one wheel (left front wheel, right front wheel, left rear wheel, right rear wheel). It is thus known from which wheel (e.g. n_{fl}: rotational speed of the left front wheel) the respective rotational speed information originates. Further, methods are known in the art

(e.g. from DE 100 60 392 A1) which are destined to localize also the pressure modules of the directly measuring tire pressure monitoring system (TPMS) which are fitted in or at the wheels. These known methods allow allocating directly measured tire inflation pressures to a wheel (e.g. P_{fl}: tire inflation pressure of the left front wheel).

[0020] The following steps are carried out in the exemplary method:

1. detecting wheel speed signals n of the vehicle wheels,
2. detecting directly measured tire inflation pressures P,
3. learning at least one reference value depending on the detected wheel speed signals n at a predetermined nominal tire inflation pressure $P_{nominal}$,
4. determining a coefficient k which describes the characteristics of the vehicle tires, from wheel speed variations Δn at a tire inflation pressure variation ΔP, and
5. determining a detection threshold S that depends on tire characteristics for the improved detection of tire inflation pressure loss from the coefficient k found, from a designated critical tire inflation pressure loss ΔP_{crit} that describes a tire inflation pressure value which, when it is not reached or is exceeded, causes a warning indicating tire inflation pressure loss to be given to the driver of the vehicle, as well as from a predefined nominal tire inflation pressure $P_{nominal}$.

[0021] To carry out the method of the example it is necessary that all tires of the vehicle have the prescribed nominal tire inflation pressure, e.g. 2.0 bar. To this end, e.g. each tire is caused manually, by the driver, for example, to adopt the value of the nominal tire inflation pressure prescribed by the vehicle

manufacturer (e.g. $P_{nominalFL} = P_{nominalFR} = P_{nominalRL} = P_{nominalRR} = 2.0$ bar). Alternatively, it is also possible to have the existing tire inflation pressure checked by the directly measuring tire pressure monitoring system (TPMS) as to whether the prevailing tire inflation pressure corresponds to the nominal tire inflation pressure. Subsequently, the exemplary method is started e.g. by actuating a reset key button. In the so-called learning phase, the reference values, e.g. DIAG, SIDE, AXLE of the indirectly measuring tire pressure monitoring system are learned from the wheel speeds n and saved.

$$DIAG = \frac{n_{FL} + n_{RR}}{n_{FR} + n_{RL}} - 1 = \frac{n_{FL} + n_{RR} - n_{FR} - n_{RL}}{n_{FR} + n_{RL}},$$
$$SIDE = \frac{n_{FL} + n_{RL}}{n_{FR} + n_{RR}} - 1 = \frac{n_{FL} + n_{RL} - n_{FR} - n_{RR}}{n_{FR} + n_{RR}}, \qquad (1)$$
$$AXLE = \frac{n_{FL} + n_{FR}}{n_{RL} + n_{RR}} - 1 = \frac{n_{FL} + n_{FR} - n_{RL} - n_{RR}}{n_{RL} + n_{RR}},$$

n_{FL}, n_{FR}, n_{RL}, n_{RR} represent the rotational speeds of the wheels ,front left', ,front right', ,rear left' and ,rear right' at a nominal tire inflation pressure $P_{nominal}$.

[0022] After completion of the learning phase, the changes of at least one reference value, e.g. ΔDIAG, with regard to the learned value are identified, for example:

$$\Delta DIAG = \frac{\Delta n_{FL} + \Delta n_{RR} - \Delta n_{FR} - \Delta n_{RL}}{n_{FR} + n_{RL}}, \qquad (2)$$

[0023] As this occurs, the individual wheel speed variations Δn basically depend on the tire inflation pressure variations ΔP of the associated wheels.

[0024] The wheel speed variations Δn are insignificant and proportional to the pressure variations ΔP in a first approximation:

$$\frac{\Delta n}{n} \approx k \cdot \frac{\Delta P}{P_{nominal}} \qquad (3)$$

$\Delta P / P_{nominal} = (P_{actual} - P_{soll}) / P_{nominal}$, (e.g. $\Delta P_{FL} / P_{nominalFL} = (P_{actualFL} - P_{nominalFL}) / P_{nominalFL}$; with $P_{actualFL}$: measured actual tire inflation pressure of the left front wheel; $P_{nominalFL}$: when learning the adjusted nominal tire inflation pressure of the left front wheel). The change of the reference value (e.g. ΔDIAG) is a linear combination of the pressure variations, for example:

$$\Delta DIAG = k_{FL} \cdot \frac{\Delta P_{FL}}{P_{nominalFL}} + k_{RR} \cdot \frac{\Delta P_{RR}}{P_{nominalRR}} - k_{FR} \cdot \frac{\Delta P_{FR}}{P_{nominalFR}} - k_{RL} \cdot \frac{\Delta P_{RL}}{P_{nominalRL}} \qquad (4)$$

[0025] After N tire pressure variations, N reference values, herein ΔDIAG values, and N $\Delta P/P_{nominal}$ values exist in the system. The coefficients k_{FL}, k_{FR}, k_{RL}, k_{RR} are calculated on the basis of the regression method (method of least squares). The higher N is, the more precise the coefficients k_{FL}, k_{FR}, k_{RL}, k_{RR} are calculated, this is why the coefficients k_{FL}, k_{FR}, k_{RL}, k_{RR} are newly calculated after each new tire inflation pressure variation. When the coefficients k_{FL}, k_{FR}, k_{RL}, k_{RR} were determined separately for each wheel, the detection thresholds S for the indirectly measuring tire pressure monitoring system are determined depending on the coefficients k_{FL}, k_{FR}, k_{RL}, k_{RR} for each wheel. To this effect, a critical tire inflation pressure loss ΔP_{crit}, e.g. $\Delta P_{crit} = 0.5$ bar, or e.g. $\Delta P_{crit}/P_{nominal} = 25$ % is defined, upon the exceeding of which

value the driver shall be alerted. A nominal tire inflation pressure of $P_{nominal}$ = 2.0 bar has been made the basis in this example, and a warning shall be output when an actual tire inflation pressure of $P_{actual} = P_{nominal} - \Delta P_{crit}$ = 2.0 bar - 0.5 bar = 1.5 bar is not reached. Thus, when taking the equation (4) into account, there appears at least one critical reference value, herein $(\Delta DIAG_{crit})_{xy}$, for the wheel 'xy' of:

$$(\Delta DIAG_{crit})_{xy} = k_{xy} \cdot \frac{\Delta P_{crit}}{P_{nominal}} \qquad (5)$$

[0026] As the driver shall be alerted when the critical reference value, herein $\Delta DIAG_{crit}$ is exceeded, it will thus apply for the detection threshold S for the wheel 'xy':

$$S_{xy} < \left|(\Delta DIAG_{crit})_{xy}\right| \qquad (6)$$

[0027] When all of the wheels have equal or almost equal characteristics, the approximation ratio can be used:

$$k \approx k_{FL} \approx k_{FR} \approx k_{RR} \approx k_{RL} \qquad (7)$$

[0028] When the wheels have different coefficients, a coefficient that is averaged on the basis of the different coefficients is used for the further calculations.

[0029] Thus, the equations (6) and (7) allow determining the detection threshold S of the indirectly measuring tire pressure monitoring system in consideration of the tire characteristics (represented by the coefficient k):

$$S < \left| k \cdot \frac{\Delta P_{crit}}{P_{nominal}} \right| \quad (8)$$

[0030] In some types of vehicles it is also feasible that the tire type (e.g. summer tire, winter tire, or all-season tire) and the tire dimensions (e.g. width, height, rim diameter) can be input using a special function of a multi-function display or in the workshop, e.g. by means of the vehicle diagnostic unit. This information (tire type, tire dimensions) can be submitted to the indirectly measuring tire pressure monitoring system. Based on this information, the indirectly measuring tire pressure monitoring system will adapt the detection thresholds regarding tire pressure loss in view of the existing tire type and the tire dimensions.

[0031] Another possibility involves reading the information about the tire type and the dimensions from a unit mounted into the tire, e.g. from a magnetic bar code, or a transmitting unit such as a transponder.

[0032] The detection thresholds and other parameters of tire pressure check systems can be calculated depending on the transmitted tire parameters. For example, the detection threshold S is determined according to the following equation:

$$S = S_0 \cdot A \cdot B \quad (9)$$

with

S_0: normal detection threshold which describes a detection threshold for a designated tire type with designated dimensions,

A: a function of the tire type (winter tire, summer tire, all-season tire etc.), B: a function of the tire dimensions (e.g. width).

[0033] Another possibility involves saving a data base of the tires and of the associated parameters of the tire pressure monitoring system in a vehicle control unit (10), for example, in the electronic brake control unit (ECU).